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THE DISPOSAL SYSTEMS EVALUATION FRAMEWORK FOR DOE-NE

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The Used Fuel Disposition (UFD) Campaign within DOE-NE is evaluating storage and disposal options for a range of waste forms and a range of geologic environments. For each waste form and geologic environment combination, there are multiple options for repository conceptual design. The Disposal Systems Evaluation Framework (DSEF) is being developed to formalize the development and documentation of options for each waste form and environment combination.

The DSEF is being implemented in two parts. One part is an Excel workbook with multiple sheets. This workbook is designed to be user friendly, such that anyone within the UFD Campaign can use it as a guide to develop and document repository conceptual designs that respect thermal, geometric, and other constraints. The other part is an Access relational database file that will be centrally maintained to document the ensemble of conceptual designs developed with individual implementations of the Excel workbook.

The DSEF Excel workbook includes sheets for waste form, environment, geometric constraints, engineered barrier system (EBS) design, thermal, performance assessment (PA), materials, cost, and fuel cycle system impacts. Each of these sheets guides the user through the process of developing internally consistent design options, and documenting the thought process. The sheets interact with each other to transfer information and identify inconsistencies to the user. In some cases, the sheets are stand-alone, and in other cases (such as PA), the sheets refer the user to another tool, with the user being responsible to transfer summary results into the DSEF sheet. Finally, the DSEF includes three top-level sheets: inputs & results, interface parameters, and knowledge management (references). These sheets enable users and reviewers to see the overall picture on only a few summary sheets, while developing the design option systematically using the detailed sheets.

The DSEF Access relational database file collects the key inputs, results, and interface parameters from each Excel workbook implementation. The power of a relational database is available to sort and organize groups of designs, and to answer queries about what evaluations have been done in the UFD Campaign.

I. INTRODUCTION

This work is based to a large extent on the results of the Used Fuel Disposition (UFD) Campaign workshop held in Albuquerque, NM, January 28 – 29, 2010. Subsequent to the workshop, a series of brainstorming sessions resulted in a recommendation to develop a Disposal Systems Evaluation Framework (DSEF) to formalize the development and documentation of options for each waste form and environment combination. That recommendation was discussed with colleagues and managers at ANL and SNL, and LLNL was authorized to develop an initial description of the DSEF concept. The recommendation was also discussed with colleagues at INL in the DOE-NE Fuel Cycle Technology(FCT) Systems Analysis Campaign.

II. OVERVIEW OF THE DSEF

The DSEF uses a logical process for developing one or more disposal system concepts (also referred to as repository systems in this paper) for any given waste form and geologic setting combination. Figures 1 and 2 show the relationship of the DSEF to the DOE NE fuel cycle Campaigns, and Figure 3 provides an overview of the DSEF itself.

Current categories of waste form, disposal system environments, and engineered barrier system (EBS) design concepts that are being studied are listed in Tables

1, 2, and 3 respectively. Each of these categories could be subdivided further as studies become more detailed.

The DSEF encompasses several decision-support analysis categories (note that the framework can provide links to the corresponding analysis toolkits).

- High-level simulator of waste-isolation performance of the disposal system. This is not a Total System Performance Assessment (TSPA), which will be developed separately. The DSEF looks at waste hazard durations, regulatory requirements, and existing performance assessments to give a very high-level rough estimate of performance.
- Sorter of disposal-system attributes (pros and cons). It is anticipated that the DSEF will be exercised for multiple disposal system concepts for many of the combinations of waste forms and disposal-system environments. Thus, a compilation of pros and cons for each situation will aid in grouping and contrasting various options.
- High-level estimator of disposal-system cost. This uses high-level estimating tools benchmarked to existing detailed cost estimates or actual costs.
- High-level thermal-analysis toolkit to assess geometric requirements (footprint, drift spacing, waste-package spacing, and waste package capacity) for the disposal system, based on specified thermal criteria (e.g., limits on peak temperatures of engineered components and the near-field). Once a geologic setting and waste form are selected for evaluation, thermal analysis is key to defining potential disposal-system layouts (single level, multi-level, in-drift, horizontal borehole, vertical borehole, deep borehole from the surface, etc.) and EBS concepts (capillary barrier, clay barrier, etc.). Early attention has been focused on the thermal tools.
- High-level assessment of overall system impacts of a disposal concept. The disposal system is one component of the overall fuel cycle. As such, it must interface with other components that may influence the disposal system design requirements. One goal of the DSEF is to integrate with higher-level systems analysis tools being used and developed in the FCT arena.

The DSEF has also established a UFD Campaign knowledge management system to organize high-level information, data, and assumptions, thereby facilitating consistency in high-level system simulation and economic analyses. This system is housed with the Idaho National Laboratory (INL) - based documentation system. Attention has been given to lessons learned from the systems used at the Waste Isolation Pilot Plant (WIPP) and the Yucca Mountain Project (YMP). Where reference material from other programs (e.g., international) is used or cited, the knowledge-management system imports the reference material directly or refers to it in bibliography form. Alternative data sets (e.g., from other programs) are also utilized to evaluate their influence on DSEF analyses for given waste form and disposal system combinations. The knowledge management system also includes the database component of the DSEF, which is used to maintain the results of DSEF realizations, enabling the comparison and ranking of various combinations of waste form, disposal system, environment, and disposal system design options. Finally, the UFD Campaign knowledge management system can provide a compendium of "templates" to be utilized, in a labor-efficient fashion, to build parallel DSEF analyses (e.g., "one offs").

The DSEF is a stand-alone, push-the-button and wait for the results, item of software. It uses Microsoft Office Excel to guide the user through a logical process of evaluating combinations of waste form, disposal system environment, and disposal system design. The DSEF database will initially use Microsoft Office Access to compile results. In later stages, the DSEF database results could be transferred to software developed in the field of knowledge engineering and knowledge management systems (Ref. 2).

At certain points in the logical process, the DSEF software will point the evaluator to other software tools to do analyses needed to move the process forward. The developers of DSEF have been mindful to make it no more complex than necessary to evaluate the system being considered, so that it is useful to a broad range of analysts. The DSEF organizes and documents the work such that multiple realizations for different combinations can be compared and contrasted using the Excel realizations directly or using the Access database.

III. WASTE FORMS

The DSEF team is using a catalog (developed by the larger UFD Campaign team and by other DOE-NE Campaigns) of potential waste forms. These include the waste forms listed in Table 1. The DSEF assembles summary information about waste form and waste package combinations. Waste form parameters include heat/volume ratio, heat/mass ratio, and waste density, as well as the mass and half lives of the radionuclides in the waste. This information will interface with the FCT

Systems Analysis Campaign "VISION" model of nuclear fuel cycles and material flows, the Separations and Waste Forms Campaign waste stream and waste form descriptions, as well as the Waste Form, EBS, Natural Systems and FEPS work packages in the UFD Campaign (Figure 1).

IV. GEOLOGIC SETTING

The DSEF team uses geologic parameters (such as thermal conductivity) for the disposal-system setting that are needed to calculate thermal performance. These parameters are used to determine whether a disposal-system concept provides sufficient heat removal to respect temperature limits of the waste form, EBS components, and near-field. The DSEF team is using a catalog of geologic parameters for each disposal-system setting (assembled by the larger UFD Campaign team), which are needed for a rough estimate of disposal-system performance. These parameters include porosity, permeability, and rock composition.

V. DISPOSAL-SYSTEM CONCEPT AND THE EBS

As noted in Tables 2 and 3, a number of options for disposal-system concept are being considered. The size of the waste package (capacity) and the spacing (between waste packages and between drifts or deep boreholes) are key factors to meeting thermal limits.

For each combination of waste form parameters and geologic setting parameters, a set of disposal system design options is being identified. Each option of the set will be a separate realization of the DSEF.

TABLE 1. Waste Forms

Category	Sub-category
Used Nuclear Fuel (UNF)	Commercial Spent Nuclear Fuel (CSNF) with nominal burnup: Uranium (U) & mixed oxide (MOX) from Light Water Reactors (LWRs)
	CSNF with high burnup: U & MOX, >50% burnup without reprocessing, such as in some fusion-fission hybrids
	High Temperature Gas Reactor (HTGR) fuel using TRISO/graphite elements: Large volume, low volumetric heat, and higher burnup than LWRs
	DOE Spent Nuclear Fuel (DSNF): U metal from N-reactor, and carbides & oxides
High-Level Waste (HLW) Glass	Current borosilicate glass: Includes processing chemicals from original separations, with U/Pu removed, but minor actinides and Cs/Sr remaining
	Potential borosilicate glass: No minor actinides and/or no Cs/Sr. Mo may be removed to increase glass loading of radionuclides. This waste form has a lower volumetric heat rate
HLW Glass Ceramic / Ceramic	Glass-bonded sodalite from Echem processing of EBR-11, and from potential future Echem processing of oxide fuels
	An advanced waste form that includes iodine volatilized during chopping, which is then gettered during head-end processing of used fuels
HLW Metal Alloy	Metal alloy from Echem: Includes cladding as well as noble metals that did not dissolve in the Echem dissolution
	Metal alloy from aqueous reprocessing: Includes undissolved solids and transition metal fission products
Lower Than HLW (LTHLW)	Includes Classes A, B, and C, as well as Greater Than Class C (GTCC)
Other	Molten salt, electro-chemical refining waste, new waste forms, and radionuclides removed from other waste forms (e.g. Cs/Sr, I, C)

TABLE 2. Disposal-System Environments

Category	Description
Surface Storage	Long-term interim storage at reactors or at centralized sites
Shallow Disposal	Depths <= 100 m (e.g., near-surface disposal, LTHLW sites)
Mined Geologic Disposal (Hard Rock, Unsaturated)	Unsaturated Zone (UZ): Granite/crystalline or tuff (Depths > 100 m)
Mined Geologic Disposal (Hard Rock, Saturated)	Saturated Zone (SZ): Granite/crystalline or tuff (Depths > 100 m)
Mined Geologic Disposal (Clay/Shale, Saturated)	SZ: Clay/shale (Depths > 100 m)
Mined Geologic Disposal (Salt, Saturated)	SZ: Bedded or domal salt (Depths > 100 m)
Deep Borehole Disposal	Granite/crystalline (Depths ~ 1000 m or deeper)
Other	Examples include deep seabed, and carbonates

TABLE 3. Engineered Barrier System (EBS) Concepts

Category	Sub-category
EBS Emplacement Options	Large waste packages in drifts
	Horizontal or vertical borehole emplacement from drifts
	Deep boreholes
EBS Barrier Options	Waste form
	Cladding
	Barriers internal to the waste package
	The waste package itself
	Drip shields or Liner Materials
	Backfill
	Buffer materials
	Sorptive materials
	Seals above deep boreholes

Fig. 1. Relationship of DSEF to DOE NE Campaigns. Note: The DSEF is developed within the UFD Campaign and is used by all three Campaigns (SA, SE, and UFD)

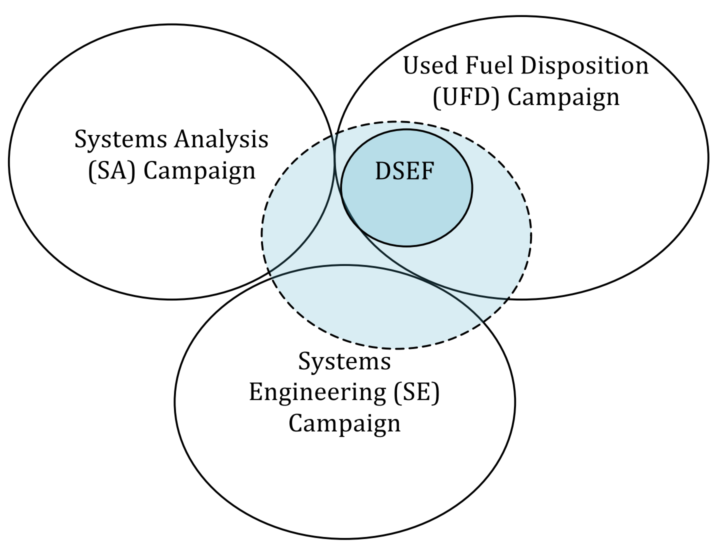


Fig. 2. The Systems Analysis Campaign model hierarchy interface with the DSEF

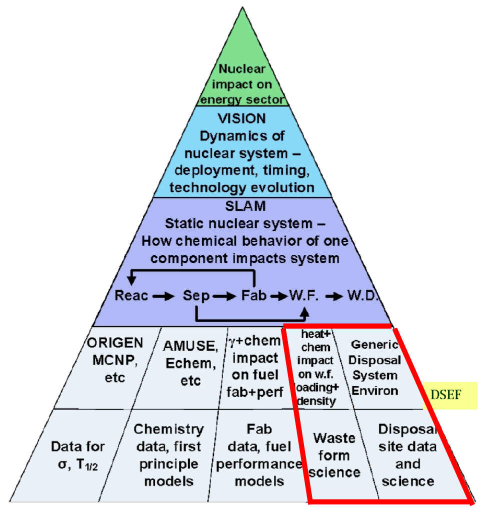
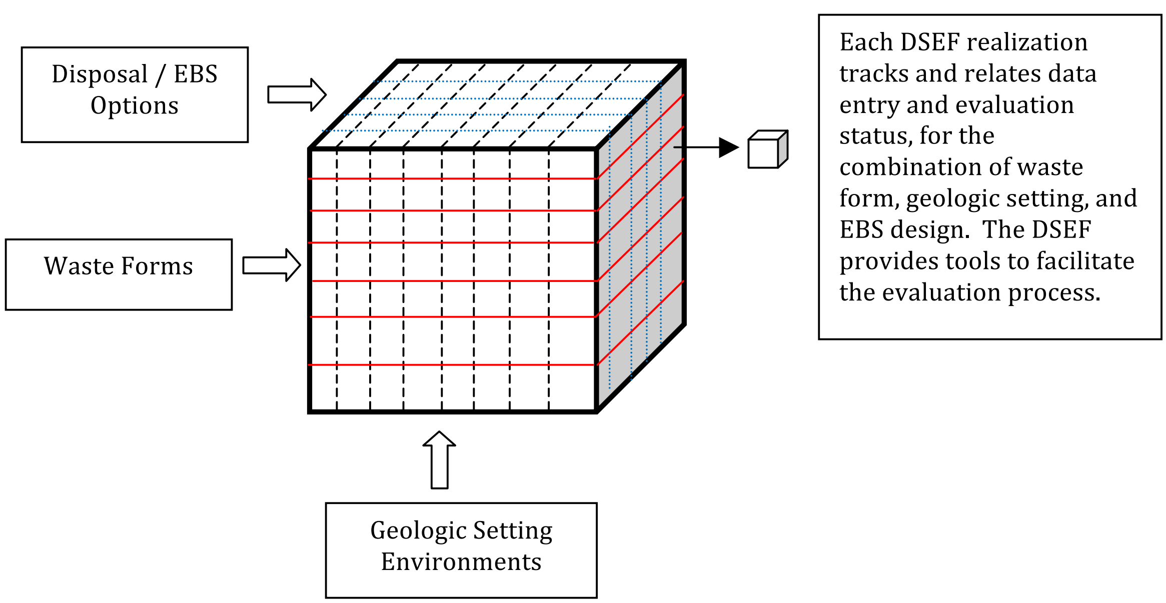


Fig. 3. The Disposal Systems Evaluation Framework addresses combinations of waste form, geologic setting, and design



The DSEF Team is developing a thermal analysis toolkit that can evaluate thermal performance with a range of levels of sophistication. This will enable labor- and computationally-efficient initial calculations, followed by more accurate calculations for some of the more significant combinations of waste form, geologic setting, and disposal system design. Thermal analysis toolkit options include analytic solutions to simplified geometries, the model developed by Argonne National Laboratory (ANL) for GNEP and AFCI, and the Lawrence Livermore National Laboratory (LLNL) 3D finite element engineering code TOPAZ.

The results of the thermal analyses determine the required disposal system (e.g., repository) footprint for that waste form (type and quantity) and geologic setting. In turn, the disposal system footprint and design provide much of the information needed for the high level cost estimate.

A catalog of candidate materials for the engineered barriers is being developed by LLNL. Metals are being evaluated based on an extension of the LLNL Degradation Mode Surveys developed for Yucca Mountain. Other barrier materials (clay, backfill, etc.) are initially using information developed in other repository programs worldwide.

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